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# Spring and Springbrook Fauna of the Piceance Basin, Colorado

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# SPRING AND SPRINGBROOK FAUNA OF THE PICEANCE BASIN, COLORADO

by

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## FOREWORD

Our nation is confronting a mandate to develop synthetic fuels from oil shale to reduce dependence on foreign oil supplies and as a substitute for decreasing natural gas reserves. Oil shale deposits in the United States are among the richest and most extensive in the world. Achieving the level of synthetic fuel production necessary to significantly contribute to U.S. energy supplies requires establishment of many facilities devoted to oil-shale retorting. Each of these facilities may produce complex waste waters containing numerous organic and inorganic contaminates.

To adequately determine potential effects of contaminated waste water effluents in aquatic environments, background data is needed. This report contains background information (July 1978 - August 1980) on the aquatic environment surrounding Oil-Shale Tract C-b in Piceance Basin. This report will aid research scientists and others concerned with baseline information on the aquatic environment and how it may be impacted by development of an oil shale industry.

Leonard Mueller, Project Officer
Environmental Research Laboratory-Duluth

## ABSTRACT

The aquatic macroinvertebrates of Willow Creek, Piceance Creek, Stewart Gulch, and spring sources surrounding Tract C-b in the Piceance Basin were sampled from July 1978 through August 1980 as part of a baseline monitoring program prior to oil-shale development. Macroinvertebrate species lists are included in this report. The spring sources exhibited a somewhat different and more constant physical and chemical environment compared to the streams. The more constant conditions in the springs allowed a generally greater density and biomass of macroinvertebrates than in the other study streams. Species compositions were also different. There were differences in the macroinvertebrate community structure at each of the sites in the streams, apparently caused by differences in flow patterns, substrate type, and influence by spring sources. The spring sources had distinct communities despite generally similar environmental conditions. Different slopes of the springs were the eminent cause of macroinvertebrate differences between springs. A discussion of major potential impacts resulting from development of oil-shale upon aquatic macroinvertebrates in springs and springbrooks surrounding mining Tract C-b is presented.

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# SECTION I

## INTRODUCTION

The Piceance Basin is located in northwestern Colorado northwest of the city of Rifle, and southwest of the city of Meeker (Figure 1). The basin is characterized by north to northeast-trending ridges and valleys. Elevations in the study area range from 1900 to 2100m with local reliefs of over 100m. The area is semi-arid; total annual precipitation ranges from 30 to 51 cm. Temperatures range from minus 40 C to 40 C (Weeks et al. 1974).

Natural vegetation of the valleys and slopes consists primarily of big sagebrush (*Artemesia tridentata*), which forms associations with grasses, forbs, or other shrubs. The ridges and northfacing slopes are dominated by a pinyon (*Pinus edulis*)-juniper (*Juniperus osteosperma* and *Juniperus scopulorum*) woodland. Hay is grown on irrigated land in the stream valleys, but plant coverage for the entire basin averages only 25% of the land's surface (U.S. Department of the Interior 1973).

The largest known oil resource in the world lies in the oil-shale deposits of the Green River Formation in Colorado, Wyoming, and Utah. This resource has stimulated governmental and industrial interest in developing oil-shale extraction technology (Weeks et al. 1974; Myers et al. 1977). In 1974, the U.S. Department of the Interior leased two tracts of public land in the Piceance Basin to stimulate oil shale development (Tracts C-a and C-b). Mining and processing facilities are currently under construction on these tracts. The present study was only concerned with springs and streams near Tract C-b.

Previous studies of the macroinvertebrate fauna in aquatic habitats near Tract C-b include those by Everhart and May (1973), Pennak (1974), Woodward-Envicon Inc. (1975), consultants to Shell Oil Company (C-b Oil Shale Project, 1976a), and Gray and Ward (1977, 1978, 1979). However, very little work has been done in springbrook habitats near the tract.

The effect of area springs in providing important water quality characteristics to streams was recognized by Gray and Ward (1977, 1978). The water flowing from the springs is provided by two main aquifers which are separated by a 30m confining layer termed the Mahogany Zone. The upper aquifer is primarily within the Uinta Formation (sandstones and marlstones), which forms the surface rock. The lower aquifer is located in the Parachute Creek Member of the Green River Formation. The lower aquifer is highly saline (up to 30,000 mg/l T.D.S.), principally due to nahcolite ($NaHCO_3$). The Mahogany Zone separates the upper and lower aquifers both chemically and hydraulically, except in recharge and discharge areas. Recharge areas are generally above an altitude of 2,130m; water discharges from the upper aquifer to the alluvium of the valley floors and through springs along the valley walls (Weeks et al. 1974).

Figure 1. Location and boundaries of the Piceance Basin, Colorado.

The springs and springbrooks will provide excellent locations to monitor groundwater quality as oil-shale development proceeds. The development plan at Tract C-b has been changed from the Tosco II process to a modified extraction method. The new technique involves mining 10 to 30% of the shale to create retort chambers. The remaining shale above the chamber is then fractured and retorted in place (Energy Research and Development Administration, 1977). This process is to be carried out in the Mahogany Zone.

The locations of the sampling sites are shown in Figure 2. WC-2 was approximately 1m wide, 10cm deep, and had a rubble substratum. WC-1 was similar in depth; however, it was wider and had a sand-silt substratum. There were some emergent macrophytes at WC-1 (*Rorippa nasturtium-aquaticum* and *Veronica salina*, but WC-2 was limited to a small amount of submerged macrophytes (*Zannichellia palustris*).

SP-1 was approximately 1.5m wide; depth was variable (2-15cm) depending upon the amount of emergent macrophyte growth. The substrate was primarily rubble. SP-2 formed a small pool below the emergence area due to low gradient. The entire channel became choked with macrophytes during summer, and the low gradient allowed an accumulation of silt except at the emergence area. The macrophytes influenced water depth to a greater degree than at SP-1. In contrast, the substrate of SP-3 was rubble-boulder. Width near the multiple sources was approximately 5m; depth was not influenced by macrophytes, though macrophyte growth was heavy during summer.

PC-1 and PC-2 were approximately 4-5m wide. PC-1 had a cobble substrate and little algal growth. PC-2 had a predominantly rubble-boulder substrate which supported large mats of algae (mainly *Cladophora* during the summer.

SG-1 was located approximately 100m below the springs which provided year-round flow to Stewart Gulch. The site was about 0.5m wide and supported fairly dense growths of emergent macrophytes. The substrate was mainly silt-gravel.

## Characteristics of Springs

The variability of physico-chemical factors at or near a spring source is low compared to the lotic environment some distance from the source (Sloan 1956; Minckley 1963; Minshall 1968; Ward and Dufford 1979). Springs are generally rich in carbon dioxide due to the breakdown of subterranean organic matter by microorganisms and have a low pH as the excess carbon dioxide forms a weak acid (Hynes 1970). Dissolved oxygen is also usually low at spring sources (Odum 1957; Teal 1957; Minckley 1963; Ward and Dufford 1979).

Spring sources contain fewer species of macroinvertebrates compared to downstream areas that have greater physico-chemical variability (Sloan 1956; Minckley 1963; Minshall 1968; Tilly 1968). This may be due to temperature (Minshall 1968; Lehmkuhl 1972), oxygen (Sloan 1956), or other parameters, which due to their relative constancy, fail to provide cues necessary for initiation or completion of the life cycles in some species (Ward 1976; Ward and Stanford 1979). Species able to withstand the unique conditions of a spring are likely to have reduced competition and may exhibit greater density and biomass than at areas farther downstream (Sloan 1956; Minckley 1963; Minshall 1968; Tilly 1968). Sloan (1956) stated that the diversity and numbers of organisms inhabiting spring

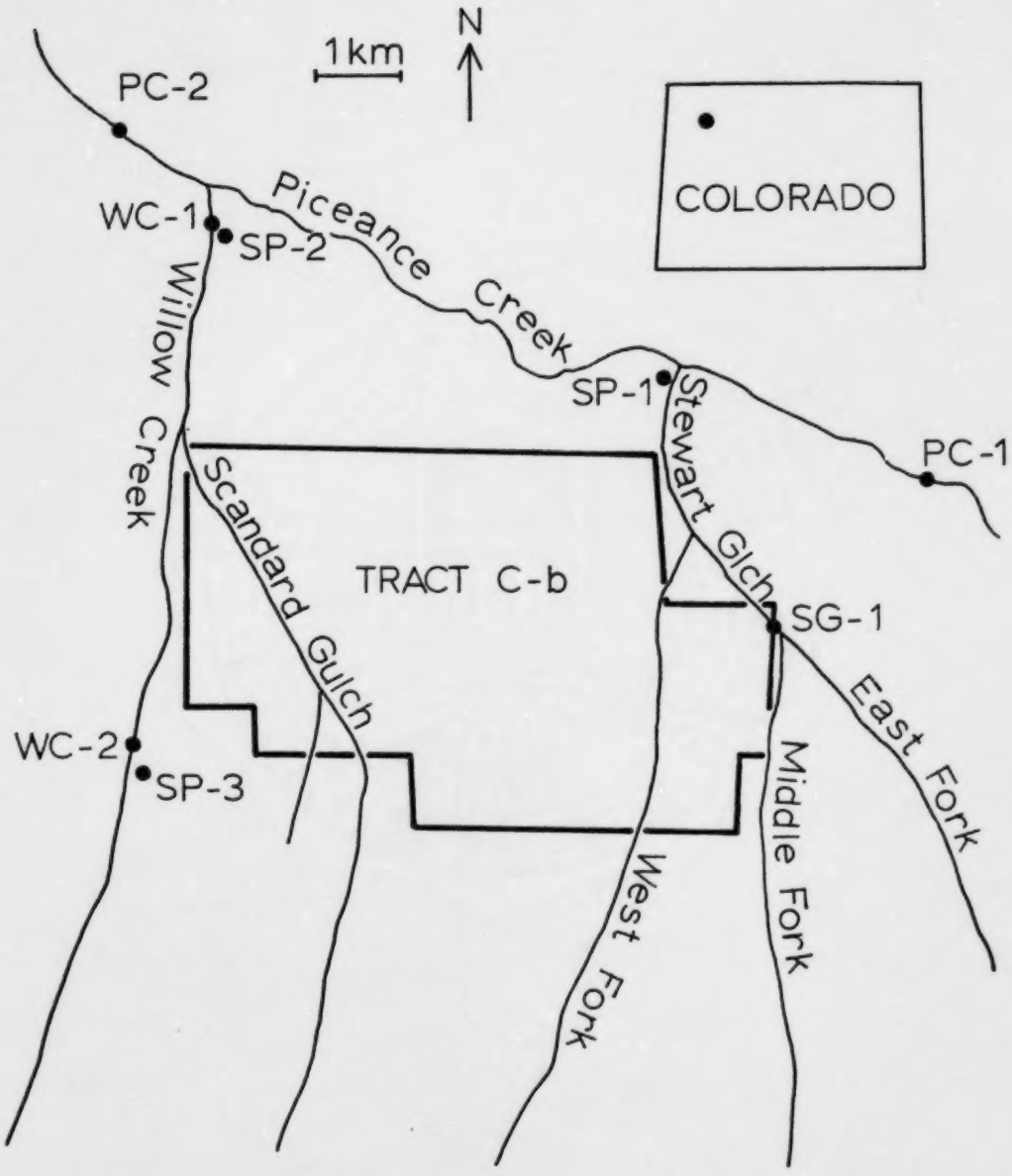


Figure 2. Locations of the sampling stations surrounding Tract C-b, in the Piceance Basin, Colorado.

communities resemble communities located in areas of organic enrichment, a situation also reported below hypolimnial release reservoirs (Ward 1974, 1976) which in some ways resemble springs (Ward and Short, 1978).

The objectives of this study were

1. To determine the macroinvertebrate community structure of spring sources and spring brooks surrounding Oil-Shale Tract C-b.

2. To provide baseline data from the above habitats prior to oil-shale development.

3. To continue monitoring Piceance Creek above and below Tract C-b.

## SECTION II

## CONCLUSIONS AND RECOMMENDATIONS

1. The spring sources exhibited more constant physical and chemical conditions and generally supported greater numbers and biomass of macroinvertebrates than sites in Piceance Creek, Stewart Gulch, and Willow Creek.

2. The sites in Willow Creek, Piceance Creek, and Stewart Gulch had quite different physico-chemical conditions resulting in different macroinvertebrate communities. The major regulating variables appeared to be flow patterns, substrate type, and proximity to spring sources.

3. The three study springs were similar in most physical and chemical variables measured, yet contained distinct macroinvertebrate communities. Differing stream-bed slopes allowed the development of such communities.

4. Monitoring of springbrook macroinvertebrates and physico-chemical variables (especially dissolved salts and flow) should be continued as oil-shale development proceeds.

5. Additional research is necessary concerning substances contained in spent oil-shale from the modified *in-situ* process and their effects upon aquatic macroinvertebrates.

## SECTION III

## MATERIALS AND METHODS

### Physical and Chemical Variables

Dissolved oxygen, free $CO_2$, pH, temperature, stream width, depth, and current were measured in the field. Dissolved oxygen was determined using the azide modification of the Winkler method. Free $CO_2$ was determined by titration according to Standard Methods (American Public Health Association et al. 1976). A Hellige color comparator was used for pH. Temperature was measured with a mercury field thermometer and by maximum-minimum thermometers. All thermometers were calibrated at 0 C in a distilled water ice bath.

Samples for analysis of bound $CO_2$, dissolved and suspended solids, nitrate-nitrogen, and other ions were transported to the laboratory on ice. Determination of bound $CO_2$ was carried out by the methyl orange method described in Pennak (1949). Nitrate-nitrogen was determined on a Spectronic-20 Colorimeter (Lind, 1979). Total suspended solids (T.S.S.) and total dissolved solids (T.D.S.) were determined by filtration (Millipore membrane filters, 0.45 m), and evaporation of 500 ml water samples (Ward, 1974). Substrate samples were collected from the spring sources and Willow Creek sites in May 1979 and brought to the laboratory for analysis. The samples were analyzed by methods outlined by Cummins (1962) and separated into the following size classes: < 0.075mm, 0.075-0.139mm, 0.139-0.5mm, 0.5-2.36mm, 2.36-3.5mm, 3.5-12.7mm, 12.7-24.4mm, 24.4-50.8mm, and > 50.8mm.

### Macroinvertebrates

Samples were collected from July 1978 to August 1980. The spring sources and Willow Creek sites were sampled monthly, except for July and August 1979. The remaining sites were sampled on a quarterly basis.

The spring sources were sampled with a coring device 46cm long and 10.16cm in diameter. The top of the core was fitted with a removable top to facilitate sample extraction. After the core penetrated the substrate to a depth of 5cm, a brass plate was forced beneath the sampler to form a bottom seal, and the enclosed substrate was removed. Excess water was screened through a 275µm mesh sieve. Four replicates were taken within 2m of a source on each sampling date.

The remaining sites were sampled with a coring device 70cm long and 20.32cm in diameter, the same diameter used in a previous study of Piceance Creek conducted by Gray and Ward (1978). The core was held in position while bottom materials were removed by hand and washed through a 275µm mesh hand net until organisms were no longer retrieved. Three replicates were taken at each of the sites in Willow Creek and Steward Gulch; five replicates were taken at the sites in Piceance Creek. All samples were preserved in the field with 5% formalin and later tranferred to 80% ethanol.

Identifications were based primarily upon keys of Usinger (1956), Edmondson (1959), Mason (1973), and Pennak (1978). Additional references used for identifications included keys of Johannsen (1969), Brinkhurst and Jamieson (1971), Nimmo (1971), Beck (1976), Brown and White (1978), Edmunds et al. (1976), Holsinger (1976), Baumann et al. (1977), Wiggins (1977), Merritt and Cummins (1978), Johnson (1978), Webb (1977), White (1978), Wu and Brandauer (1978), Morihara and McCafferty (1979), and Szczytko and Stewart (1979).

Biomass (wet weight) was determined by displacement in a graduated centrifuge tube, assuming a specific gravity of 1.0 (a close approximation). This technique allows comparison with other Piceance Basin studies (Everhart and May 1973; Pennak 1974; Gray and Ward 1977, 1978). Species diversity values were calculated using the Shannon-Weaver index shown in Weber (1973).

## SECTION IV

## RESULTS AND DISCUSSION

### Physical-Chemical Variables

The spring sources had lower concentrations of dissolved and suspended substances compared to the other locations (Table 1). Dissolved oxygen and pH were also lower in the spring sources. Generally, a wider range of annual and diel conditions occurred as the distance from a spring source increased. However, the summer growths of emergent macrophytes at the spring sources caused a considerable annual change of physical conditions in some cases.

The three springs conform to many of the generalized physico-chemical characteristics attributed to spring sources by Minkley (1963) and Hynes (1970) (e.g. slight variability, low [$O_2$], and high [$CO_2$)]. The chemical conditions of the springs were also very similar (Table 2). Of these data, only the dissolved oxygen concentrations are appreciably different. The C-b Shale Oil Project (1976b) list $HCO_3$, $SO_4$=, $Ca^{++}$, and $Mg^{++}$ as the major ions in springs 1 and 3. The data from the present study show $Na^{+}$ to also be a major constituent. Although most of the physico-chemical data show the springs to be very similar, the macroinvertebrate communities were vastly different. Explanations for this anomaly will be explored in the macroinvertebrate section.

### Benthic Macroinvertebrates

A total of 120 macroinvertebrate taxa were collected at the sampling stations surrounding Tract C-b (Appendix). The Diptera comprised approximately 43% of the total numbers of taxa; the next largest percentage belonged to the Coleoptera (12%).

A listing of the major taxa collected is shown in Table 3. The flatworm *Polycelis coronata* and water mites (Hydracarina) were characteristic of spring sources. *Polycelis coronata* is a cold stenotherm, and water mites are very often associated with aquatic vegetation such as was found in the springs (Pennak 1978). The mollusks *Pisidium nitudum* and *Physa*, the caddisfly *Hesperophylax consimilis*, and the dipterans *Dicranota* and *Tipula commiscibilis* tended to have greater densities at and near spring sources. As a group, chironomids had the most consistent density pattern of all taxa; however, no single chironomid genus had similar densities at all sites.

The springs and Stewart Gulch site were generally dominated by Diptera and non-insects such as Amphipoda, Turbellaria and Mollusca (Figures 3 & 4). The large percentage of biomass shown for the Diptera was due primarily to *Tipula commiscibilis*, a large shredder (Merritt and Cummins 1978). The compositions of macroinvertebrates at the sampling stations in Willow Creek and Piceance Creek

Table 1. Selected physical and chemical characteristics of aquatic habitats in the study area.

| Variable | Spring sources | Willow Creek | Upper Stewart Gulch | Piceance Creek |
|---|---|---|---|---|
| T.D.S. mg/l | 680[b] | 934[c] | 926[c] | 749[c] |
| T.S.S. mg/l | 4[b] | 291[c] | 75[c] | 504[c] |
| Temp. range C[a] | 6-10 | 0-18.5 | 7-10 | 0-21 |
| pH range[a] | 7.1-7.3 | 7.1-8.2 | 7.2-7.4 | 7.0-8.4 |
| Dissolved $O_2$ mg/l range[a] | 3.5-8.0 | 6.3-10.8 | 6.0-8.9 | 7.4-11.8 |
| Mean width m[a] | 2.4 | 1.6 | 0.6 | 4.5 |
| Mean depth cm[a] | 8.4 | 11.7 | 4.1 | 18.5 |
| Substratum | Silt-boulder | Silt-cobble | Silt-gravel | Gravel-cobble |
| Macrophyte growth | Heavy | Medium | Medium | Light |
| Spring runoff scour | No | Lower areas | No | Yes |

[a] From field measurements.

[b] From laboratory analysis (means).

[c] From 1980 U.S.G.S. data (means).

Table 2. Selected chemical characteristics of the spring sources.

| Variable | Spring source | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| T.D.S. mg/l[a] | 730 | 673 | 636 |
| Free $CO_2$ mg/l[a] | 23 | 24 | 25 |
| Dissolved $O_2$ mg/l[b] | 6.7 | 5.4 | 4.2 |
| pH range[b] | 7.1-7.3 | 7.1-7.3 | 7.2-7.3 |
| Specific conductance[c] | 1413 | 1550 | 1325 |
| Alkalinity as $CaCO_3$[c] | 378 | 437 | 402 |
| $HCO_3^-$[c] | 456 | 531 | 489 |
| $SO_4^=$[c] | 373 | 375 | 283 |
| $Cl^-$[c] | 6.9 | 9.9 | 9.6 |
| $Na^+$[c] | 130 | 134 | 119 |
| $Mg^{++}$[c] | 74 | 84 | 70 |
| $Ca^{++}$[c] | 70 | 75 | 89 |

[a] From laboratory analysis (means).

[b] From field measurements (means) except pH.

[c] Data from R.K. Skogerboe, CSU Chemistry Dept. All values (means) are mg/l except specific conductance which is shown in micromhos/$cm^3$ at 25C.

Table 3. Mean densities (organisms/m ) of common taxa at area sampling stations (July 1978-August 1980) (+indicates < org./$m^2$).

| Taxon | SP-1 | SP-2 | SP-3 | WC-1 | WC-2 | PC-1 | PC-2 | SG-1 |
|---|---|---|---|---|---|---|---|---|
| *Baetis tricaudatus* | 10 | 8 | 48 | 566 | 1580 | 1388 | 2039 | 180 |
| *Isoperla quinquepunctata* | 3 | - | 945 | 78 | 412 | 300 | 212 | 92 |
| *Amphinemura banksi* | - | - | 701 | 1 | - | - | - | - |
| *Hesperophylax consimilis* | 187 | 1056 | 948 | 20 | 200 | 26 | 38 | 159 |
| *Heterlimnius corpulentus* | 9425 | - | 3 | + | 2 | - | - | - |
| *Tipula commiscibilis* | 224 | 230 | 650 | 44 | 85 | 40 | 45 | 175 |
| *Dicranota* sp. | 476 | 253 | 674 | 25 | 244 | 54 | 24 | 214 |
| *Simulium arcticum* | - | 3 | 2 | 349 | 209 | 192 | 386 | 1647 |
| Chironomidae | 4012 | 3550 | 904 | 6504 | 2859 | 4127 | 5998 | 2608 |
| *Gammarus lacustris* | 628 | 960 | - | 11 | 2 | + | 2 | 2315 |
| *Polycelis coronta* | 2639 | 301 | 5031 | 2 | 15 | - | - | 289 |
| *Physa* sp. | 1060 | 1887 | 5 | 81 | 165 | 12 | 10 | 19 |
| *Pisidium nitidum* | 3 | 2919 | 9 | 39 | 36 | - | - | 2 |
| Oligochaeta | 3000 | 11243 | 4397 | 21378 | 57 | 3426 | 3404 | 4911 |
| Hydracarina | 1865 | 2212 | 433 | 7 | 29 | + | 19 | 22 |

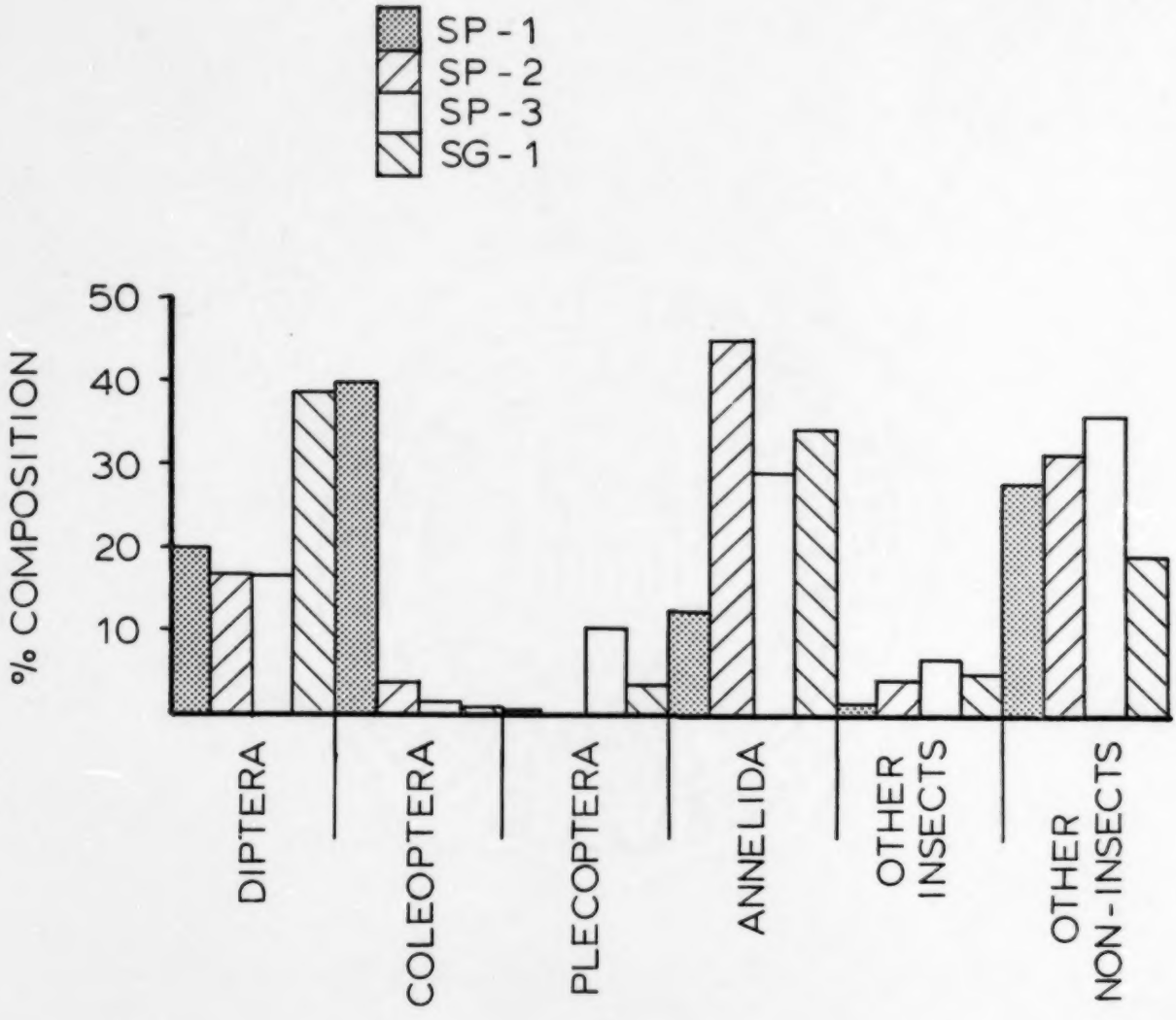


Figure 3. Percentage composition (density) of major invertebrate groups in Piceance Basin springs and upper Stewart Gulch site.

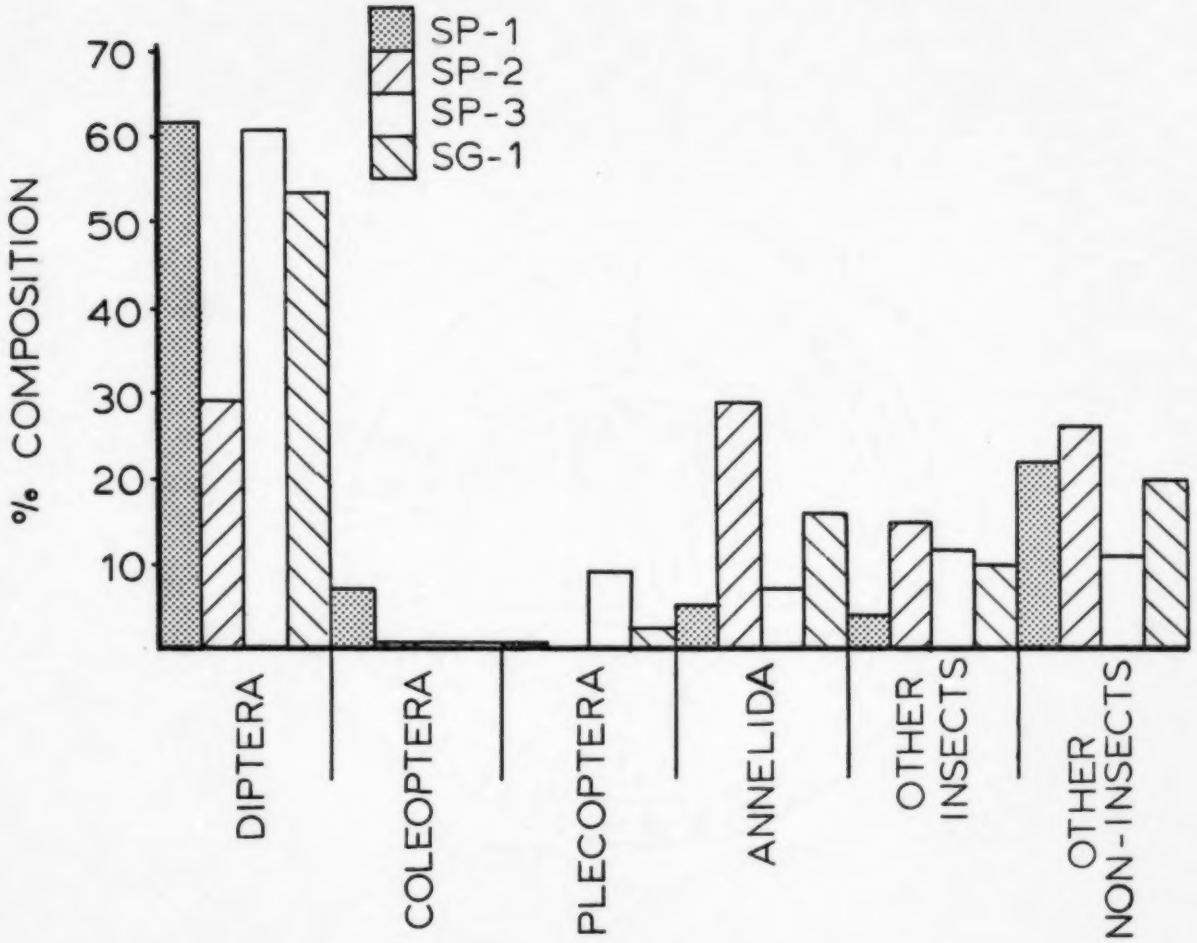


Figure 4. Percentage composition (biomass) of major invertebrate groups in Piceance Basin springs and upper Stewart Gulch site.

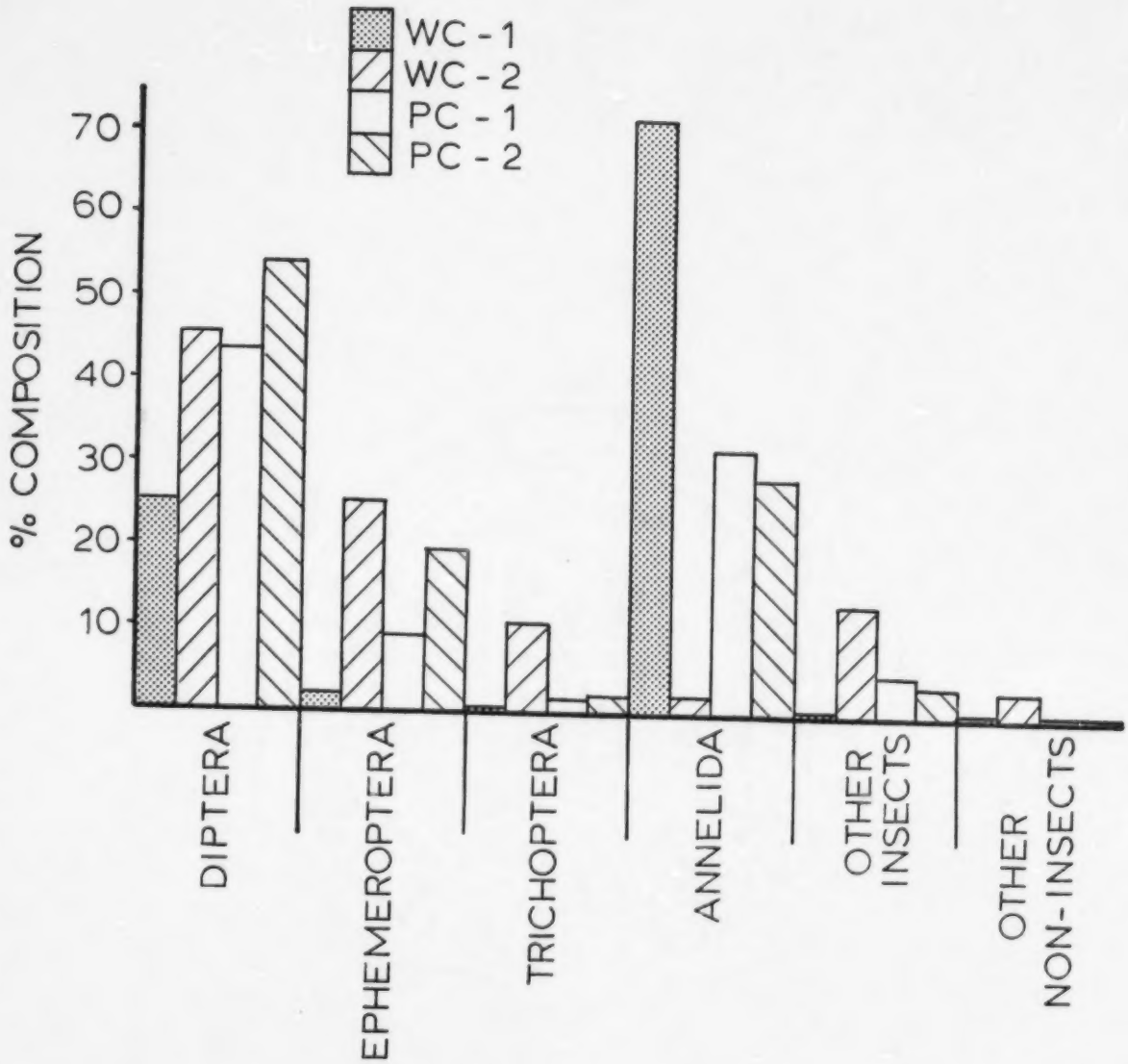


Figure 5. Percentage composition (density) of major invertebrate groups of the Willow Creek and Piceance Creek sites.

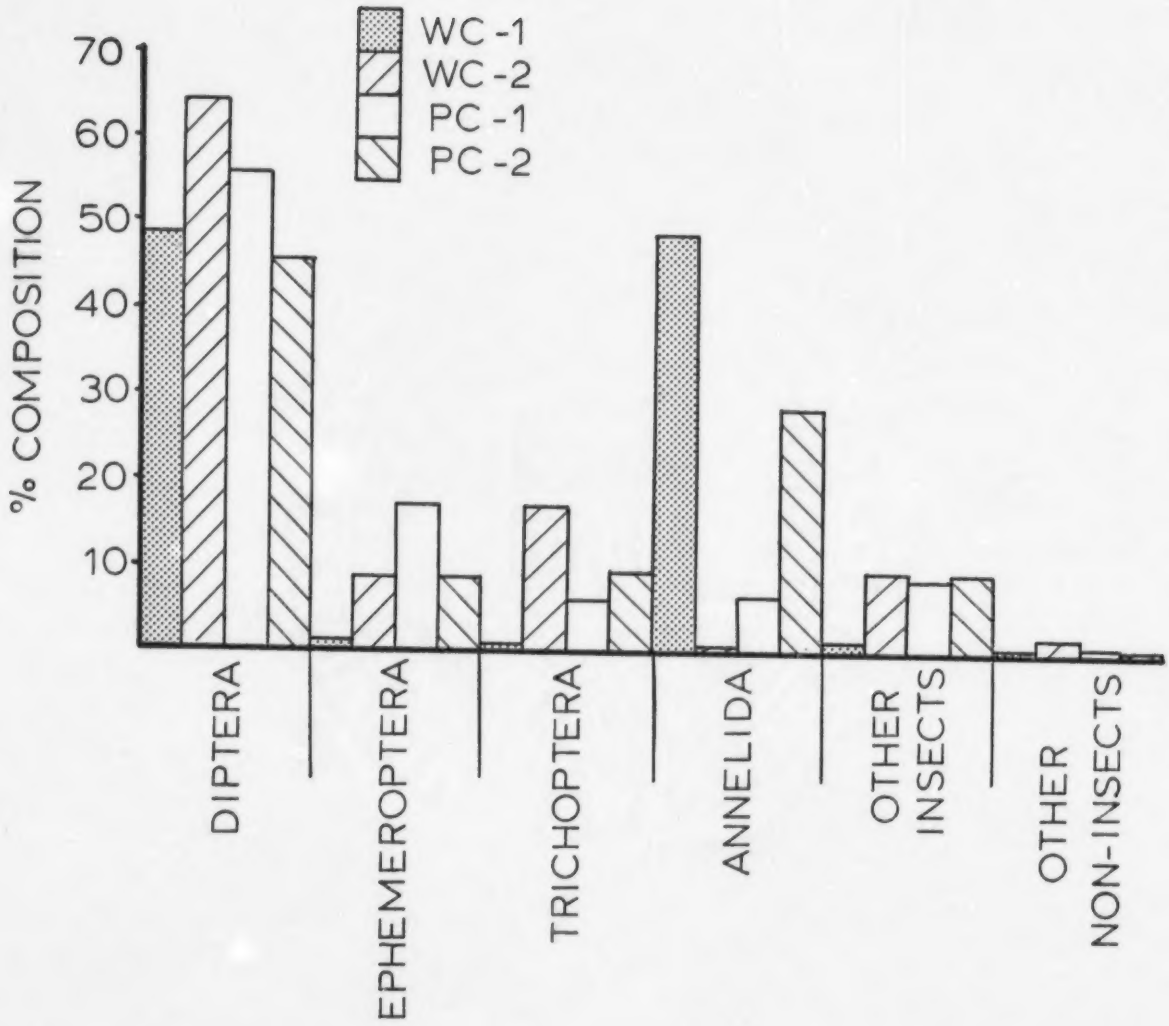


Figure 6. Percentage composition (biomass) of major invertebrate groups at the Willow Creek and Piceance Creek sites.

differed from those in the springs and Stewart Gulch site by the general absence of non-insect groups other than annelids (Figures 5 & 6). The heavy growth of aquatic macrophytes near the springs provided an excellent refuge for many non-insect taxa (e.g. Amphipoda, Molluska, and Hydracarina). Ephemeroptera were more important at the Willow Creek and Piceance Creek sites, but a large percentage of the density and biomass was again contributed by Diptera. Due to its soft substrate, WC-1 was almost completely dominated by dipterans and annelids. WC-2, PC-1, and PC-2, though largely comprised of Diptera, had important contributions from other insect orders such as Ephemeroptera.

Generally, the springs had greater density and biomass than the other sites (Table 4). SG-1 was located near the permanent source of that stream, and thus had some characteristics that were similar to the spring sources. Several investigators have shown that spring sources contain greater density and biomass, but lower diversity than downstream areas (Minckley 1963, Minshall 1968, Vannote et al. 1980). In the present study, diversity values for the springs are generally lower than values found at downstream locations. Overall, the diversity values indicate unpolluted conditions at most of the stations. Wilhm (1970) found that unpolluted water usually had Shannon-Weaver values between 3.0 and 4.0.

An increase in diversity was expected as distance from the springs increased, but did not occur (Table 4) in all cases due to site-specific circumstances. Ice formation, scour, and irrigation activities probably limit the fauna of Piceance Creek (Gray and Ward, 1978); WC-1 contained a sand-silt substrate (Table 5) which was conducive to chironomids and tubificid worms (Hynes 1970), but did not allow the presence of a diverse fauna such as that found at WC-2 (which had a rubble substratum, Table 5). Rubble substrate has been shown to support a more diverse community than sand (Brusven and Prather 1974; Ward 1975). WC-1 and WC-2 were influenced by inflowing springs which prevented ice formation and provided high quality water, thus the substrate differences (and concurrent water velocity differences) probably allowed the more diverse macroinvertebrate community at WC-2.

The communities of the springs and the other sampling stations were quite different. The more constant conditions in the springs may have prevented the initiation or completion of the life cycles of some species. The effect of constant temperature has been discussed by Tilly (1968), Lehmkuhl (1972, 1979), Ward (1974, 1976) and Ward and Stanford (1979). Those organisms that can survive may be able to expand their populations because of reduced competition (Tilly 1968; Ward and Stanford 1979) and the rare occurrence of catastrophes such as floods. The heavy macrophyte growth in the springs provided a refuge for some species, but may discourage egg laying by aerially colonizing adult insects. For example, our sampling program produced open areas in the summer canopy of macrophytes and the numbers of the mayfly were considerably higher in the second year of study. The virtual absence of suspended particles in the springs is not conducive to filter-feeding organisms. Drift patterns may also be important. There are no upstream sources of macroinvertebrates for the springs other than the phreatic zone. Finally, site-specific factors may also be important. For example, a small reservoir (with a one meter waterfall at its outlet) located between SP-3 and WC-2 probably eliminates upstream movement of immature benthic organisms from Willow Creek into the spring.

Table 4. Summary of macroinvertebrate variables from area sampling stations (July 1978-August 1980).

| Site | Number/$m^2$ [a/] | Biomass wet weight/$m^2$ [a/] | Total number of taxa | Diversity [b/] |
|---|---|---|---|---|
| SP-1 | 23937 | 107.9 | 67 | 3.0 |
| SP-2 | 26196 | 117.5 | 66 | 2.5 |
| SP-3 | 15158 | 92.1 | 63 | 3.2 |
| WC-1 | 29745 | 33.1 | 80 | 2.2 |
| WC-2 | 7599 | 32.6 | 77 | 4.0 |
| PC-1 | 10580 | 14.4 | 61 | 3.6 |
| PC-2 | 12052 | 19.3 | 59 | 3.1 |
| SG-1 | 14543 | 76.4 | 63 | 4.0 |

a/ Grand mean.

b/ Shannon-Weaver index.

Table 5. Substrate data for Willow Creek and the spring sources (samples collected in May 1979).

| Site | Median phi value[a/] by weight lies between | Size in mm |
|---|---|---|
| SP-1 | -1.24 to-3.67 | 2.37 to 12.7 |
| SP-2 | 3.74 to 1.0 | 0.075 to 0.5 |
| SP-3 | -4.6 to <-5.7 | 24.4 to >50.8 |
| WC-1 | 2.85 to -1.24 | 0.139 to 2.37 |
| WC-2 | -1.8 to -4.6 | 3.5 to 24.4 |

a/phi value = $-\log_2$ of the particle size diameter in millimeters.

The spring sources differed considerably with regard to predominant taxa (Table 3). The stoneflies *I. quinquepunctata* and *A. banksi* were abundant at SP-3, but were virtually absent from the other springs. The elmid beetle *H. corpulentus* contributed the highest numbers of any taxon at SP-1, but was rare at the other sites. *P. nitidum* was numerically very important at SP-2, but had low densities at the other springs.

The springs had similar temperatures, chemical factors (e.g. pH), size, and amount of emergent aquatic macrophytes. However, they differed greatly in stream-bed slope. SP-3 had a high gradient, SP-2 had a low gradient, and SP-1 was intermediate. The substrate particle sizes parallel gradient differences between springs (Table 5). Also, water depth and velocity were seasonally affected by the macrophytes at SP-1 and SP-2. Water in the high gradient SP-3 continued to flow in a similar year-round pattern regardless of the presence of macrophytes. The slope of SP-2 was so low that the fine detritus created after autumnal dieback of macrophytes was never flushed downstream. The present data appear to indicate that substrate type and the pattern of water flow are the most important factors influencing the macroinvertebrates found in the springs.

Potential Impact of Oil Shale Development at Tract C-b Upon Macroinvertebrates of Springs and Springbrooks

The major sources of potential water pollution from development of oil shale are: 1. sediments from spent shale and construction areas, 2. dissolved salts leached from spent shale piles or from underground saline water, 3. changes in the quantity of water due to alterations in the aquifer system, and 4. toxic substances (e.g., heavy metals and organic compounds) leached from spent shale piles or released by an accidental spill. A report concerning the potential impacts to Piceance Creek has been prepared by Gray and Ward (1977).

The influence of substrate type on aquatic macroinvertebrates is well documented (e.g., Cummins 1966; Thorup 1966; Brusven and Prather 1974; Ward 1975, Rosenberg and Wiens 1978; Farnworth et al. 1979). Results of these studies show that gravel-rubble substrate supports a more diverse community than sand or silt. When sand (or silt) is added to rubble substrate, it fills interstices and blankets rock surfaces. This reduces food resources and attachment sites (Nuttall and Bielby 1973; Resh 1977), which reduces the number and variety of organisms inhabiting the substratum (Chutter 1969; Nuttall 1972; Davis 1980a).

As less surface disturbance is expected with the modified *in-situ* method, problems associated with erosion and resulting sedimentation of aquatic habitats should be substantially less than those encountered with surface mining techniques. However, there is still a chance for direct introduction of sediments to area springs and streams from spent oil shale (Ward et al. 1971) and construction activities. Some spent oil shale will (due to space limitations) be stored on the surface. Stabilization of spent shales (Herbert and Berg 1978) should substantially reduce erosion problems and subsequent siltation of aquatic habitats. Airborne dust particles (from moving equipment and shale processing) may also settle or wash into aquatic habitats surrounding the mine area. Significant additions of sediment through either pathway discussed above will be likely to cause changes in aquatic macroinvertebrate communities near the mine area.

The effects of drought on stream macroinvertebrates have been documented by Hynes (1958, 1961) and Larimore et al. (1959). Organisms not adapted in some way to withstand desiccation are eliminated. Species which are found in streams liable to drought have evolved strategies that allow them to survive dry conditions, or quickly colonize dry areas after flow resumes (Hynes 1970). Current and its effects on substrate are very important to many stream dwelling species and ecological processes (Scott, 1958; Edington 1965; Hynes 1970; Wallace and Merritt 1980). Data from the present study show the importance of current in molding macroinvertebrate community structure. Large reductions or increases in flow will be expected to produce changes in the macroinvertebrate fauna.

Reductions in groundwater flow resulting from mine dewatering would affect springbrooks to a high degree. Pumping large quantities of water could change points of discharge, and continuous pumping over a number of years could dry up springs and seeps over a large portion of the basin (U.S. Department of the Interior, 1973). Weeks et al. (1974) concluded that there will be a reduction in general water discharge from springs hydraulically connected to the upper aquifer where significant drawdown occurs. Such occurrences would have drastic consequences on fauna in the springs and area streams.

Kinney et al. (1979) recognized increases in salinity as one of the major potential impacts resulting from oil shale development. Such increases in dissolved salt concentrations increase osmotic stress on macroinvertebrates (Beadle 1957). Kapoor (1979) demonstrated the lethal effects of increasing salinity on stonefly nymphs. Similar effects would probably be expected with other groups of organisms. Davis (1980b) believed the high salinity in the upper reaches of a Texas river was largely responsible for low diversity values. Within the Piceance Basin, Gray and Ward (1977, 1978) concluded that high concentrations of dissolved salts in downstream areas of Piceance Creek (which receive water from the lower aquifer) were a limiting factor to many macroinvertebrate species.

The new method of extraction may cause underground alterations of the aquifer due to the retort and placement of spent shale back into the mine. Spent shale leachate contains up to 76,000 mg/1 T.D.S. (Ward et al. 1971) compared to the 636-730 mg/1 found emerging from the study springs. A mixing of the upper and lower aquifers due to a disruption of the confining layer (Mahogany Zone) could result in highly saline water reaching surface discharge points. Also, water utilized in shale processing presents a disposal problem (Kinney et al. 1979). Either from surface runoff or underground percolation, large increases in salt concentrations will be detrimental to aquatic habitats.

There is a lack of data concerning the effects of heavy metals and complex organic substances on invertebrates from flowing waters. However, a few older ecological studies (Carpenter 1924; Jones 1940, 1958) and a growing number of recent studies (e.g., Thorp and Lake 1973; Sodergren 1976; Platts et al. 1979; Winner et al. 1980) show that additions of metals such as cadmium, copper, iron, lead, manganese, nickel, and zinc can lead to the reduction of many macroinvertebrate groups in the receiving stream. The effects of organic substances contained in oil-shale leachate upon aquatic macroinvertebrates are virtually unknown. Many of the possible accidental spill materials (e.g. diesel fuel) will be expected to have detrimental effects upon aquatic organisms if the materials enter springs and streams. The extent of the effects will depend on the type of material spilled, and the quantity of the spill.

Ward et al. (1971) presented data concerning the concentration of various metal ions in spent oil-shale, although values were not obtained from spent oil-shale leachate processed by the modified *in-situ* method. Levels of aluminum, copper, chromium, iron, magnesium, manganese, lead, and zinc were measured. Comparing these estimated levels of metals in runoff from oil-shale leachate to those from analysis of spring water (R.K. Skogerboe, CSU Chemistry Dept.), there is a high value (in the leachate) only for the macronutrient magnesium, which would not be expected to be particularly toxic to macroinvertebrates.

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Appendix. Taxa collected from the Piceance Basin sampling stations, and mean density values (July 1978-August 1980) in organisms/$m^2$.

| | SP-1 | SP-2 | SP-3 | WC-1 | WC-2 | PC-1 | PC-2 | SG-1 |
|---|---|---|---|---|---|---|---|---|
| Ephemeroptera | | | | | | | | |
| *Baetis tricaudatus* | 10 | 8 | 48 | 566 | 1580 | 1388 | 2039 | 180 |
| *Baetis insignificans* | - | - | - | 1 | 3 | 35 | 140 | - |
| *Callibaetis* | - | 14 | - | 7 | 1 | 23 | + | - |
| *Epeorus* | - | - | - | - | - | - | - | 1 |
| *Rhithrogena* | 3 | 3 | - | - | - | 2 | - | - |
| *Ephemerella inermis* | 23 | 5 | 3 | 11 | 322 | 406 | 43 | - |
| *Paraleptophlebia* | 1 | - | - | 3 | 1 | 4 | 4 | 3 |
| *Tricorythodes minutus* | - | - | - | 1 | + | 16 | 96 | - |
| Plecoptera | | | | | | | | |
| *Isoperla quinquepunctata* | 3 | - | 945 | 78 | 412 | 300 | 212 | 92 |
| *Amphinemura banksi* | - | - | 701 | - | 1 | - | - | - |
| *Zapada* | - | - | - | - | - | 2 | - | 315 |
| *Capnia* | - | - | 2 | - | 2 | 142 | 18 | 52 |
| Trichoptera | | | | | | | | |
| *Hesperophylax consimilis* | 187 | 1056 | 948 | 20 | 200 | 26 | 38 | 159 |
| *Limnephilus* | 14 | - | - | - | - | - | - | - |
| *Hydropsyche oslari* | - | - | - | 1 | 256 | 102 | 107 | 1 |
| *Glossosoma ventrale* | - | - | - | - | 336 | - | - | - |
| *Brachycentrus americanus* | - | - | - | + | 4 | - | 15 | - |
| *Hydroptila* | - | - | - | 7 | 8 | 8 | 28 | 6 |
| *Ochrotrichia* | - | 5 | 60 | 2 | - | - | 29 | 363 |

Appendix. Continued

| | SP-1 | SP-2 | SP-3 | WC-1 | WC-2 | PC-1 | PC-2 | SG-1 |
|---|---|---|---|---|---|---|---|---|
| Coleoptera | | | | | | | | |
| *Agabus* | 18 | 94 | - | 15 | 2 | 8 | 3 | 2 |
| *Copelatus* | - | 2 | - | - | - | - | - | - |
| *Oreodytes* | 87 | 745 | 8 | 2 | + | - | 2 | 60 |
| *Galerucella* | 3 | 4 | 2 | - | - | 6 | - | 5 |
| *Heterlimnius corpulentus* | 425 | - | 3 | + | 2 | - | - | - |
| *Optioservus seriatus* | 6 | - | 8 | - | 555 | 44 | 215 | - |
| *Zaitzevia parvula* | - | - | - | - | - | - | - | - |
| *Stenelmis* | 1 | - | - | + | - | - | - | - |
| *Cleptelmis* | - | - | 1 | - | - | - | - | - |
| *Microcylloepus pusillus* | - | - | - | - | - | - | 1 | - |
| *Brychius* | 6 | 5 | - | 3 | + | 34 | 27 | 2 |
| *Cymbiodyta* | - | 3 | - | + | + | 2 | - | - |
| *Helophorus* | 1 | 1 | 1 | + | - | - | - | - |
| *Hydrobius* | 1 | 27 | - | + | 2 | - | - | - |
| Odonata | | | | | | | | |
| *Ophiogomphus severus* | - | - | - | - | - | + | + | - |
| *Ishnura perparva* | - | - | - | + | + | 2 | + | - |
| Lepidoptera | | | | | | | | |
| Pyralidae | 2 | 4 | - | - | - | - | - | - |
| Hemiptera | | | | | | | | |
| Corixidae | + | - | - | - | - | - | - | - |
| *Buenoa* | - | - | - | + | - | - | - | - |
| *Mesovelia* | - | 27 | 1 | + | - | - | - | - |

Appendix. Continued

| | SP-1 | SP-2 | SP-3 | WC-1 | WC-2 | PC-1 | PC-2 | SG-1 |
|---|---|---|---|---|---|---|---|---|
| Diptera | | | | | | | | |
| Tipulidae | | | | | | | | |
| *Tipula commiscibilis* | 224 | 230 | 650 | 44 | 85 | 40 | 45 | 175 |
| *Dicranota* | 476 | 253 | 674 | 25 | 244 | 54 | 24 | 214 |
| *Hexatoma* | 3 | - | - | 59 | 7 | 98 | 61 | 24 |
| *Pedicia* | 90 | 44 | 28 | + | 2 | - | - | 14 |
| *Ormosia* | 7 | 57 | 1 | 6 | 2 | + | - | 97 |
| *Limonia* | - | - | + | 5 | - | - | - | 8 |
| *Erioptera* | - | 5 | 2 | 21 | - | - | 4 | 13 |
| Ephydridae | | | | | | | | |
| *Hydrellia* | - | - | - | - | - | - | - | - |
| *Scatella* | 1 | - | 1 | 3 | + | - | - | - |
| *Ephydra* | - | - | - | - | - | + | + | - |
| Ephydridae A | - | 5 | - | - | - | - | - | 3 |
| Ephydridae B | - | 8 | - | - | - | - | - | - |
| Heleidae | | | | | | | | |
| *Palpomyia* | 3 | 49 | 7 | 226 | 9 | 34 | 37 | 450 |
| Dixidae | | | | | | | | |
| *Dixa* | 2 | 5 | 34 | 1 | - | - | - | 88 |
| Simuliidae | | | | | | | | |
| *Simulium arcticum* | - | 3 | 2 | 349 | 209 | 192 | 386 | 1647 |
| Stratiomyiidae | | | | | | | | |
| *Euparyphus* | 11 | 6 | 72 | 6 | 28 | 16 | - | 50 |

Appendix. Continued

| | SP-1 | SP-2 | SP-3 | WC-1 | WC-2 | PC-1 | PC-2 | SG-1 |
|---|---|---|---|---|---|---|---|---|
| Psychodidae | | | | | | | | |
| *Pericoma* | 20 | 57 | 72 | 8 | 2 | + | + | 24 |
| *Psychoda* | 1 | - | 27 | - | + | - | - | - |
| Tabanidae | | | | | | | | |
| *Chrysops* | - | - | 3 | + | - | - | 4 | 5 |
| Culicidae | | | | | | | | |
| *Culiseta* | - | 7 | - | - | - | - | - | - |
| Empididae | | | | | | | | |
| *Chelifera* | 3 | 5 | 9 | 4 | 6 | 2 | - | 30 |
| *Wiedemannia* | - | 47 | - | 13 | - | - | - | 8 |
| *Hemerodromia* | - | 2 | 2 | 4 | 2 | 7 | 7 | 3 |
| Dolichopodidae | | | | | | | | |
| *Hydrophorus agalma* | - | 68 | - | 44 | + | 5 | - | 33 |
| Athericidae | | | | | | | | |
| *Atherix pachypus* | - | - | 2 | - | - | - | - | - |
| Anthyomyiidae | | | | | | | | |
| *Limnophora aequifrons* | 15 | - | 8 | 156 | 13 | 22 | 32 | 49 |
| Chironomidae | | | | | | | | |
| *Cricotopus-Orthocladius* | 3664 | 102 | 272 | 2878 | 1689 | 2811 | 4721 | 448 |
| *Cardiocladius* | 37 | 37 | 28 | 347 | 220 | 99 | 113 | 633 |
| *Eukiefferiella* | 20 | 10 | 43 | 374 | 541 | 147 | 423 | 182 |
| *Corynoneura* | 97 | 5 | 260 | 227 | 7 | 10 | 2 | 146 |
| *Thienemanniella* | 22 | 5 | 56 | 117 | 139 | 54 | 6 | 294 |
| *Smittia* | 5 | - | - | - | - | - | - | - |
| *Heterotrissocladius* | 27 | 127 | 28 | 26 | 5 | - | - | 158 |

Appendix. Continued

| | SP-1 | SP-2 | SP-3 | WC-1 | WC-2 | PC-1 | PC-2 | SG-1 |
|---|---|---|---|---|---|---|---|---|
| *Micropsectra* | 22 | 1145 | 8 | 381 | 87 | 99 | 103 | 461 |
| *Rheotanytarsus* | - | - | - | 24 | 1 | 27 | 12 | - |
| *Tribelos* | 43 | 1576 | 169 | 596 | 21 | 437 | 47 | 6 |
| *Stictochironomus* | 4 | - | 1 | 1 | - | - | - | - |
| *Cryptochironomus* | - | - | - | 107 | + | 13 | 10 | - |
| *Microtendipes* | - | - | - | - | - | 7 | - | - |
| *Polypedilum* | 7 | 439 | 18 | 745 | 91 | 31 | 161 | 40 |
| *Paratendipes* | - | - | - | 3 | + | - | - | 5 |
| *Chironomus* | 10 | 44 | 6 | 1 | + | 3 | - | - |
| *Dicrotendipes* | 6 | 5 | - | - | - | - | - | - |
| *Diamesa* | 34 | 1 | 9 | 333 | + | 18 | 21 | 25 |
| *Monodiamesa* | - | - | - | - | - | 22 | - | 3 |
| *Odontomesa fulva* | 7 | 5 | - | 108 | 1 | 79 | 199 | - |
| *Psuedodiamesa* | 4 | - | 3 | 48 | 32 | - | 25 | 30 |
| *Prodiamesa olivacea* | 1 | 22 | - | 2 | + | - | 2 | 5 |
| *Ablabesmyia* | 2 | 1 | 2 | 65 | 19 | 198 | 125 | 88 |
| *Boreochlus* | - | 2 | - | - | - | - | - | - |
| **Amphipoda** | | | | | | | | |
| *Gammarus lacustris* | 628 | 960 | - | 11 | 2 | + | 2 | 2315 |
| *Hyalella azteca* | 11 | 8 | 3 | 17 | 7 | - | 4 | 187 |
| *Stygobromus* | 4 | - | - | - | - | - | - | - |
| **Tricladida** | | | | | | | | |
| *Polycelis coronata* | 2639 | 301 | 5031 | 2 | 15 | - | - | 289 |
| **Nematoda** | 5 | - | - | 1 | + | + | 9 | 2 |

Appendix. Continued

| | SP-1 | SP-2 | SP-3 | WC-1 | WC-2 | PC-1 | PC-2 | SG-1 |
|---|---|---|---|---|---|---|---|---|
| Gastropoda | 1060 | 1887 | 5 | 81 | 165 | 12 | 10 | 19 |
| *Physa* | 6 | 2 | 2 | 2 | 3 | 4 | 2 | 9 |
| *Lymnaea* | - | - | - | + | - | + | - | - |
| *Gyraulus* | | | | | | | | |
| Pelecypoda | 3 | 2919 | 9 | 39 | 36 | - | - | 2 |
| *Pisidium nitidum* | | | | | | | | |
| Hirudinea | 54 | 582 | - | 20 | 10 | 2 | 51 | 9 |
| *Helobdella stagnalis* | | | | | | | | |
| Oligochaeta | 8 | 4 | + | + | + | - | - | - |
| *Eiseniella tetraedra* | 2992 | 11239 | 4397 | 21378 | 157 | 3426 | 3404 | 4911 |
| Other Oligochaeta | | | | | | | | |
| *Limnodrilus hoffmeisteri* | | | | | | | | |
| *Tubifex tubifex* | | | | | | | | |
| *Haplotaxis gordioides* | | | | | | | | |
| *Nais* spp. | | | | | | | | |
| *Pristina* spp. | | | | | | | | |
| Hydracarina | 1865 | 2212 | 433 | 7 | 29 | + | 19 | 22 |
| *Lebertia* | | | | | | | | |
| *Sperchon* | | | | | | | | |
| *Limnochares* | | | | | | | | |
| *Arrenurus* | | | | | | | | |
| *Ljania* | | | | | | | | |
| *Porohalacarus* | | | | | | | | |
| *Hygrobates* | | | | | | | | |
| *Limnesia* | | | | | | | | |
| *Tyrrellia* | | | | | | | | |
| *Mideopsis* | | | | | | | | |
| *Tiphys* | | | | | | | | |
| *Panisus* | | | | | | | | |